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DYNAMIC BEHAVIOR OF TWO TYPES OF ENERGY DISSIPATION DEVICES "SHEAR-PANEL" AND "OVAL-SHAPED STEEL STRIPS"

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ABSTRACT

The main objective of this study is to examine the behavior of two types of energy dissipation devices, which were installed in one story, one-bay steel frames with inverted Y-shaped braces. The specimens were subjected to slowly reversed cyclic ("quasistatic") loading, to understand their behavior when subjected to a severe earthquake, analyzing their performance under inelastic response. Experiments were performed using the on-line computer test control equipment available at CENAPRED. Emphasis is placed on the capacity of the structure to sustain large deflections and to dissipate substantial energy in its inelastic range.

The advantages found when using both kinds of devices in the steel frame, comparing with the conventional braced frame are as follows: (1) High strength and high ductility can be obtained, (2) As the damage is concentrated mainly on the energy dissipation device, it could be replaced easily after an earthquake if it were necessary and, (3) The strength of a steel frame can be changed independently of the stiffness by adjusting the details of design of both kinds of dissipation devices.

KEYWORDS

Energy dissipation; energy dissipator device; oval-shaped-strips; shear-panel; passive control

INTRODUCTION

During a severe earthquake, the maximum forces acting on a structure are lower for systems that can develop inelastic behavior. This provides the designer with an economical and rational approach for the design of earthquake resistant structures. Current seismic codes recognize this fact and permit the incursion of some structural elements into the inelastic range to dissipate seismic energy. Passive energy dissipation has been found to be a convenient way of handling and controlling the inelastic yielding.

Recently, the installation of steel bracing into existing frames has been widely used for seismic retrofitting schemes; however this system has been focused mainly on the improvement of stiffness and strength of existing frames. The system treated here may be a seismic retrofitting scheme for old buildings, as well as part of the original structural system for newly constructed buildings. The system uses ductile steel inverted Y-shaped bracing with passive energy dissipation devices that could be a "Shear Panel" type (Seki *et al.*,

1988) or an "Oval-Shaped Steel Strips" type (Aguirre *et al.*, 1992), which can dissipate large amounts of seismic energy by means of inelastic deformation.

This paper describes the seismic performance of full scale steel frames with steel inverted Y-shaped bracing systems with the additional participation of each one of the two types of energy dissipators mentioned before, subjected to slowly reversed cyclic ("quasistatic") loading tests.

DESIGN CRITERIA OF STRUCTURAL SYSTEMS WITH PASSIVE ENERGY DISSIPATION DEVICES

In order to design a structural system with energy dissipation devices to resist an earthquake, it is fundamental to get a structure with enough ductility as well as adequate strength. This implies that it is necessary to dissipate energy in the inelastic range of the devices, meanwhile the beams and columns remain in the elastic range of response, under moderate and severe earthquakes. Besides, it is absolutely necessary to provide a balance of the stiffness and strength among structural elements.

Combination of strength and ductility can be used to modify stiffness, mass or strength eccentricities over a story or through the entire building, and to eliminate possible weak links. It is of fundamental importance to bear in mind that a change in the stiffness and/or mass distributions of the structure implies a modification in its dynamic properties, and a possible change in the lateral forces acting on the structure. Possible load redistribution must be checked under both gravity and lateral loads, including a careful study of the forces introduced into the foundation system.

TEST SPECIMEN AND LOADING SYSTEM

The test setup is shown in Fig. 1. The specimen was set vertically on the testing floor over a horizontal girder. One electro-hydraulic actuator was connected to the end of the beam of the frame. The component of the response displacement of the one degree of freedom was enforced by the actuator controlled by the computer system. The story displacement was measured by a digital transducer. The moment distribution in different parts of the structure was calculated from the measured strain data of numerous strain gages.

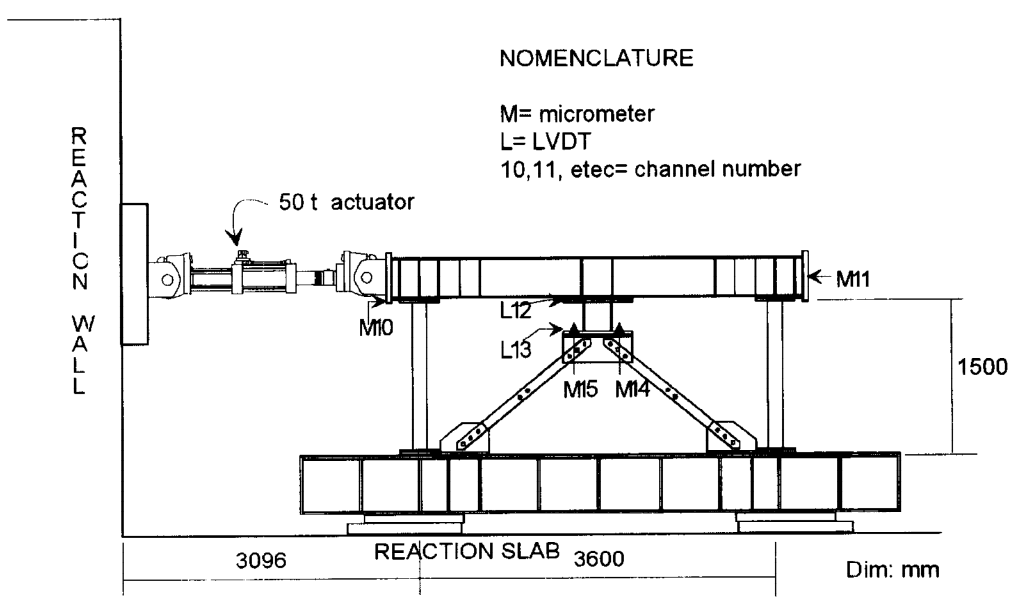

Fig. 1 Loading apparatus

SHEAR PANEL DEVICE (SPD)

The shear-panel device geometry is shown in Fig.2 and consists in a built up H-shaped steel member with thin web. This type of panel is installed between the beam and the top of brace.

The main advantages of the shear panel, besides being simple and inexpensive, are the following (*Seki et al.*, 1988) :

1. It supplies additional strength and ductility to the structural system.

2. The structural frame strength can be adjusted independently of its stiffness by means of modification of the shear panel dimensions.

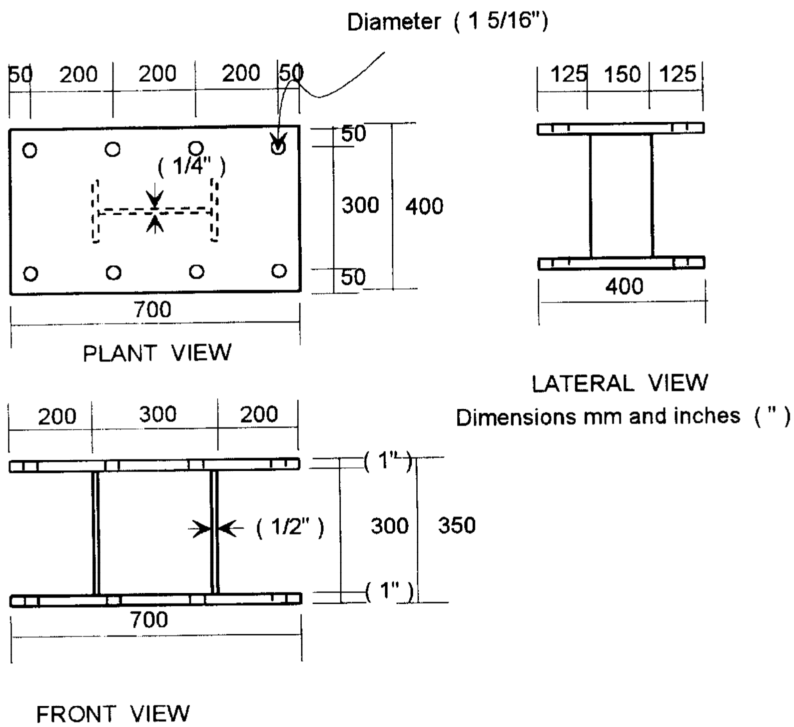

Fig. 2 Details of steel-shear-panel energy dissipation device

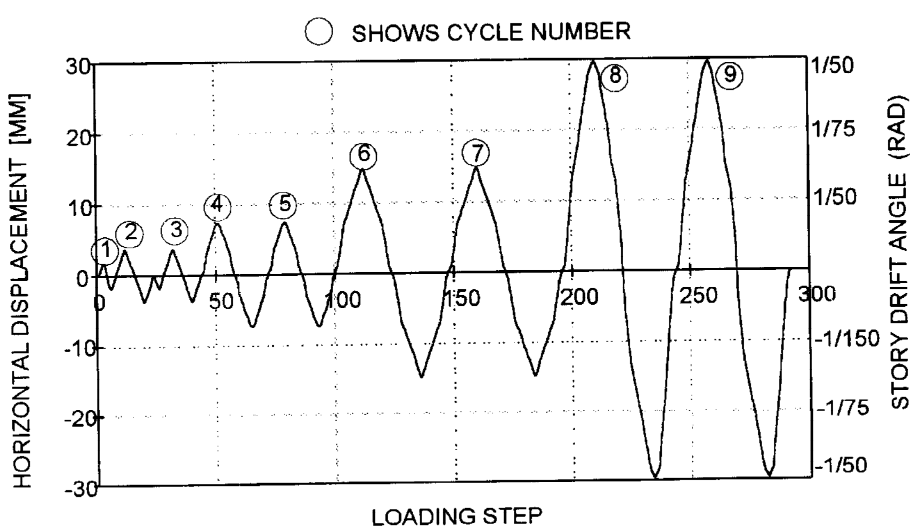

Fig. 3 Loading program

Test Results and Analysis

The load history used for the tests is represented graphically in Fig. 3. The experimental evidence obtained here clearly indicates that in terms of restoring force characteristics, Fig. 4, the ductility, strength properties and energy dissipation capacity are sufficient to withstand severe earthquake forces, because when the frame´s inter-story drift can reach 2%, the corresponding shear panel drift reaches up to 15%, and so, the main structural system response remains within the elastic range, concentrating the damage on the energy dissipation device. Nevertheless, it is absolutely necessary to inspect the Shear-Panel dissipator and replace it if needed because of local buckling and possible deterioration of welding works. It has been found experimentally that the results reported here depend directly upon the thickness of the shear panel, so the values reported can not be considered fixed. The local buckling originates the pinching of the hysteresis curve of Fig. 4.

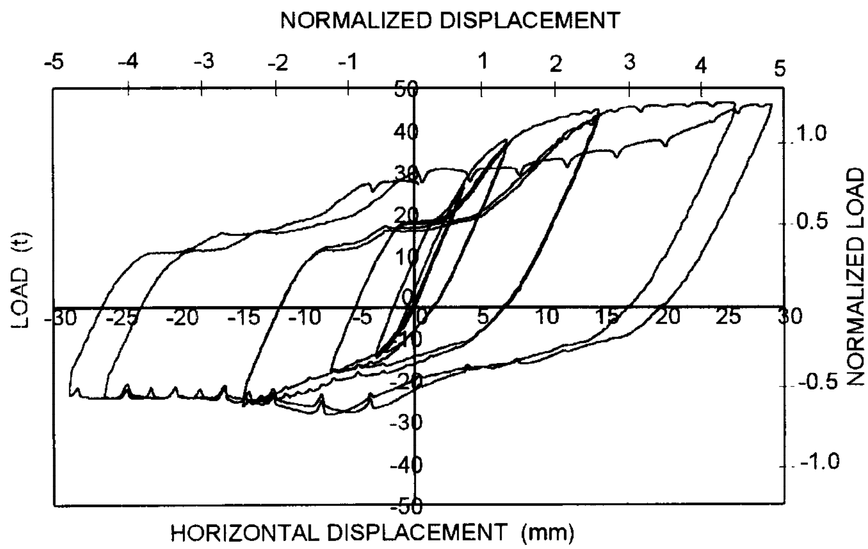

Fig. 4 Observed shear force-lateral displacement for model with shear-panel-type device

OVAL-SHAPED STEEL STRIP DEVICE (OSSSD)

This device may be designed and constructed to fit any particular specification regarding restoring force characteristics, deformation requirements and over-all size. A certain number of basic oval-shaped steel strip elements are used in the device, in this particular case, 10 elements for a nominal capacity of 35 t. The size of the device was dictated by the space available within the steel frame, which had been used previously to test the shear-panel device.

Figures 5a and 5b show the oval-shaped strip device in the process of fabrication and in its finished state, respectively. It may be noted in Fig. 5a that the oval elements were positioned horizontally to avoid yielding on the frame's upper girder for confinement, a condition that helps ensure predictability of the behavior of the elements, in terms of fatigue resistance and dissipative force development, according to the experimental data obtained by one of the authors, and reported at (Aguirre *et al.*, 1992).

When loaded, the oval-shaped strip device dissipates energy when all oval elements undergo rolling-bending, when the displacement of the frame's upper girder is followed by the device through the confining shell, which is the upper part in Fig. 5a.

In this case, the energy dissipation device was designed to allow a horizontal displacement of this particular test structural system, according to the drift limitations of the Mexico City Code (0.6%). In general, horizontal displacement limits can be adjusted to other drift limitations if needed, as well as to almost any requirements of energy dissipation .

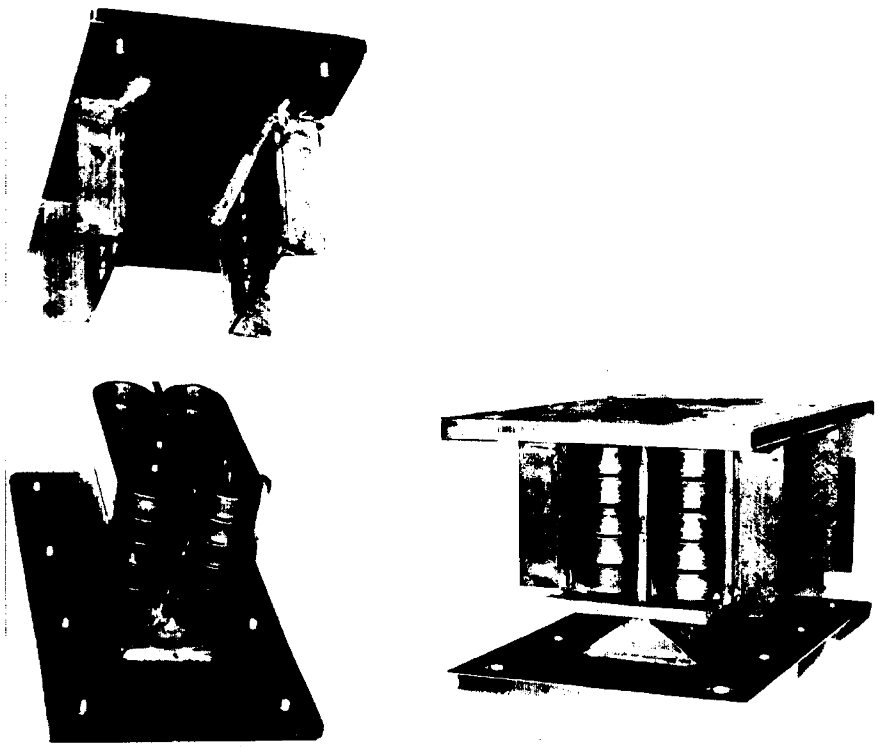

Fig.5.a Fig.5.b

Fig. 5 Details of oval-shaped-strips energy dissipation device

Test Results and Analysis

A representative hysteresis curve obtained through the tests carried out for the Oval-Shaped steel strip device is shown in Fig. 6, where it is possible to observe the restoring force characteristics, stable, symmetrical and without local buckling.

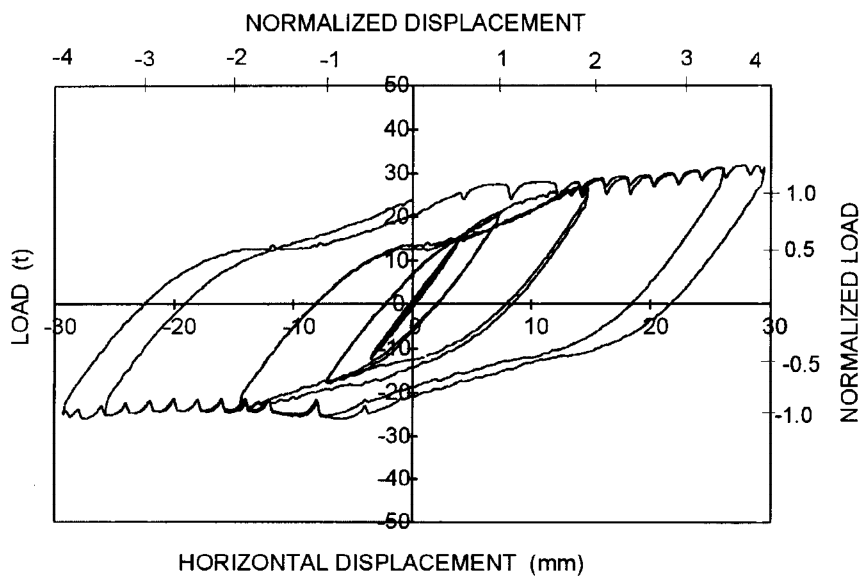

Fig. 6 Observed shear force-lateral displacement relation for model with oval-shapes-strips device

COMPARISON OF EXPERIMENTAL RESULTS FOR BOTH ENERGY DISSIPATION DEVICE TYPES

To allow comparisons of the performance of the two devices, test results were normalized with respect to its corresponding yielding point, obtained by means of its particular cyclic tests.

For the OSSSD, the positive yield point was reached at a load of 25 t, with a horizontal displacement of 7.58 mm, while the yield point for the SPD was 42.4 t with a horizontal displacement of 6 mm.

It was found that the SPD, for the particular shear panel thickness used in this case, manifested a slightly larger capacity to dissipate energy, for similar horizontal displacements, than the OSSSD, Fig. 7. Also that the SPD started energy dissipation from the second loading cycle, while the OSSSD initiated this process up to the third loading cycle.

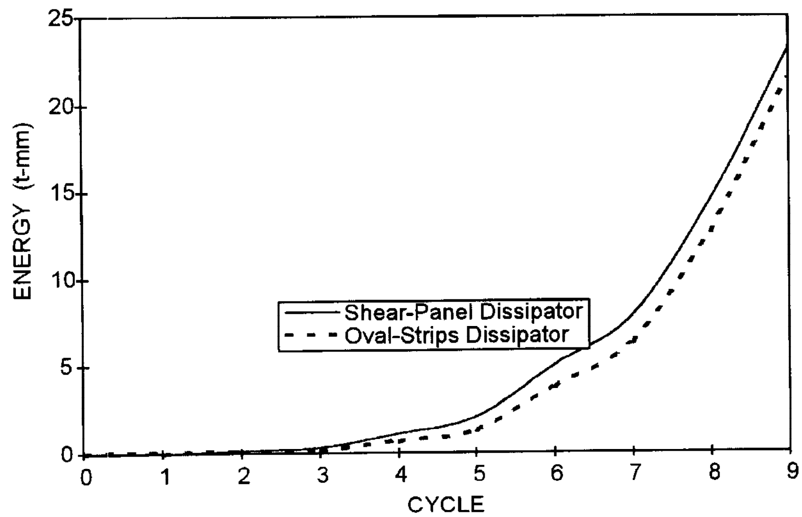

Fig. 7 Cumulative energy dissipated

On the other hand, it is important to bear in mind that the shear panel type device was practically destroyed through each one of the tests performed in the laboratory, while the same number of tests performed on the OSSSD were executed using the same device for all tests. This means that the useful life time span of the Oval-Shaped type device is longer and more reliable for a larger number of important earthquakes.

On the other hand, analyzing the representative data of Fig. 8, it is possible to infer that there is a negligible difference between the initial tangential stiffness of both devices. For 2.4 mm displacement, the different behavior begins to be noticeable. From this value on, the SPD undergoes major horizontal displacements for smaller load increments, resulting in an asymmetric response. On the other hand, the structural system with OSSSD maintains its stiffness up to the end of the test. This difference can be related to the consistency of OSSSD response.

CONCLUSIONS

As a result of quasistatic loading tests of one-story steel frames with inverted Y-shaped braces, the following conclusions were obtained:

1) For the test specimens studied here, for identical story drifts, the Shear-Panel device dissipated 9% more energy than the Oval-Shaped-Strips device. Notwithstanding, it should be noted that both types of device can be designed to dissipate as much energy as needed.

2) The Shear-Panel device reached yielding for a smaller story drift angle than the Oval-Shaped-Strips device, introducing additional hysteretic damping for smaller story drift angles of the same structural system.

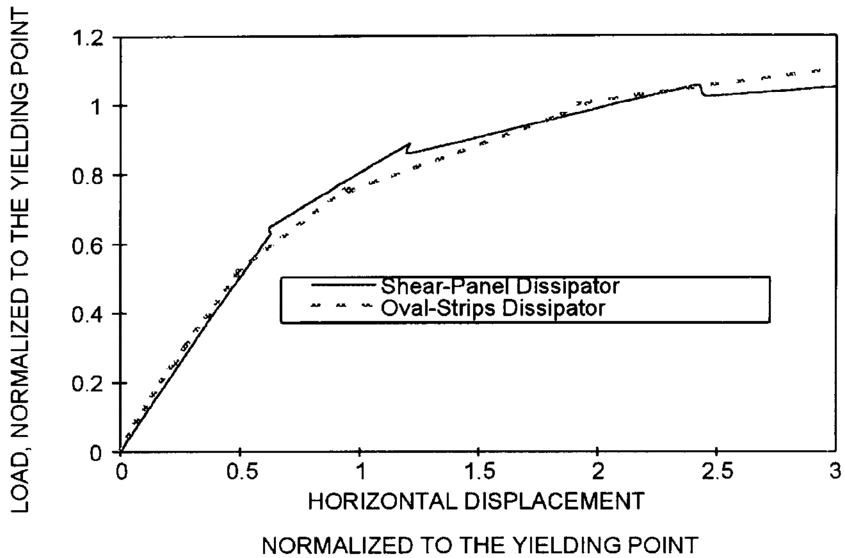

Fig. 8 Envelop curves for SPD and OSSSD

3) Due to local buckling at different points of the device itself, the Shear-Panel energy dissipator behaves asymmetrically, while the Oval-Shaped-Strips behaves symmetrically all of the time throughout the tests. This difference in performance becomes more pronounced for higher story drift angles and as the number of load cycles applied to the test specimen increases.

4) The Oval-Shaped device did not fail, can endure a larger number of load cycles and can be considered more reliable.

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